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Sorghum Response to Foliar Application of Phosphorus and Potassium with Saline Water Irrigation

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Increasing demand for fresh-water resources for urban and industrial uses is leading to limited availability of better quality water for crop irrigation. Therefore, crop response to poor quality irrigation water (e.g., saline water), and strategies to mitigate the negative effects of poor-quality irrigation water on crop yield and/or quality need to be investigated. A greenhouse experiment was conducted in the National Research Centre, Dokki, Cairo, Egypt, during the 2005 summer to evaluate the effects of different salt concentrations (tap water as control, seawater diluted to attain salinity levels of 2,500 and 5,000 ppm) and potassium (K) and phosphorus (P) foliar application (0, 50, and 100 ppm as potassium dihydrogen phosphate) on the growth, grain yield, chemical composition, and anatomical features of sorghum (Sorghum bicolor L.) *plants. Increasing irrigation-water salinity adversely affected plant growth characteristics, length and width of the vascular bundles, diameter of xylem vessels, and thickness of leaf blade mesophyl. Foliar application of P and K mitigated some of the negative effects of salinity on plant growth, and increased the concentrations of these nutrients in the leaves and grain.*

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KEYWORDS Irrigation water quality, mineral nutrition, best management practice, leaf and stem anatomy

INTRODUCTION

World resources of fresh water are getting rapidly depleted because of increasing demand for fresh water for agricultural and industrial uses. Increasing world population with elevated standard of living has contributed to greater demand for food products, which, in turn, has accelerated demand for water and other natural resources. As the freshwater resources are being depleted, attention has shifted to using lower quality water for irrigation, including reclaimed wastewater, drainage water, and diluted seawater (Deab 1998). However, management practices, including responses to nutrient management of crops irrigated with low-quality water, are not fully evaluated.

Generally, irrigation management is aimed at maximizing crop yield response as well as water-use efficiency by minimizing leaching and runoff losses. However, in the case of use of poor-quality water for irrigation, it is important to minimize adverse effects of poor quality irrigation water on soil properties, which, in turn, impacts crop production and crop quality. The suitability of irrigation water should be evaluated on the basis of local conditions in conjunction with the climatic conditions as well as soil and plant growth. Irrigation water with significant amounts of dissolved salts has both general and specific effects on crop production, which directly influences plant growth, yield, and product quality.

Sorghum (*Sorghum bicolor* L.) is becoming an increasingly important forage crop in many regions of the world. Grain sorghum is one of the most important cereal crops in Egypt, i.e., it ranks third among summer cereal crops after rice and maize in acreage and total production. As compared with maize, grain sorghum tolerates many growth-limiting factors, including heat, drought, salinity, and poor soils (El-Kady 2006). Increased tolerance of sorghum to salt has been related to its ability to overcome reduced uptake of K^+ and Ca^{2+} and/or accumulation in the leaves of toxic ions, especially Na^+ and Cl^- (Lacerda et al. 2003; Claudivan et al. 2005).

Drought- or salinity-induced negative effects on plant growth can be mitigated by leaching salts from the rootzone, by use of better quality irrigation water, soil amendments to counteract the salts built up in the soil, and foliar fertilization to overcome inadequate root uptake of nutrients (Thalooth, Tawfek, & Mohamed 2006). The objective of this study was to evaluate the effects of foliar P and K fertilization on growth, grain yield, and nutrient concentrations in the biomass of the sorghum plants irrigated by diluted seawater.

MATERIALS AND METHODS

A pot experiment was conducted in the greenhouse of National Research Centre, Cairo, Egypt, during the summer of 2005 (mean temperature range: 25°C to 38°C). Metallic pots (35 cm in diameter, 50 cm in depth), with inner surface coated with three layers of bitumen to prevent direct contact between the soil and the metal, were used. A clay loam soil was sampled (0–15 cm) from the National Research Centre Agriculture Experimental Station, Shalakan Kaluobia Governorate, air-dried and sieved to pass through a 2-mm mesh sieve. Each pot was filled with 30 kg soil, with 2 kg of the gravel particles (2–3 cm in diameter) at the bottom of the pot. Selected properties of the above soil are presented in Table 1. Sorghum cultivar 'Dorado' seeds were sown in July 2005. Plants were thinned 15 and 30 days after planting to leave three plants per pot. Each pot received 0.21 and 0.6 g P and K, respectively, as calcium super phosphate (7% P) and potassium sulfate (40% K) before planting. Nitrogen was applied as ammonium sulfate (20.5% N) at 1.4 g per pot in two equal doses, i.e., 14 and 28 days after planting.

TABLE 1 Some Physical and Chemical Properties of the Soil and Seawater used in this Study

Soil particle size analyses (%)				
Sand				
Coarse > 200 μm	Fine 200–20 μm	Silt 20–2 μm	Clay < 2 μm	Soil texture
7.20	14.25	30.22	48.33	Clay

Soil chemical analysis												
pH (1:2.5)	EC dS m^{-1} (1:5)	$CaCO_3$ %	CEC cmol kg^{-1}	OM %	Soluble cations and anions (meq 100 g^{-1} soil)							
					Na^+	K^+	Ca^{2+}	Mg^{2+}	CO_3^{2-}	HCO_3^-	Cl^{1-}	SO_4^{2-}
7.15	1.3	2.53	33.5	1.3	1.82	0.23	2.38	1.27	0.0	0.91	1.9	1.89

Available macro- and micro-nutrients (ppm)						
N	P	K	Zn	Fe	Mn	Cu
47	7.5	264.0	3.1	4.8	7.3	5.2

Chemical analysis of seawater used									
		Cations (meq L^{-1})				Anions (meq L^{-1})			
pH	EC (dS m^{-1})	Na^+	K^+	Ca^{2+}	Mg^{2+}	CO_3^{2-}	HCO_3^-	Cl^{1-}	SO_4^{2-}
8.62	33.0	393.5	20.4	26.2	118.3	0.53	9.6	253.2	295.1

Treatments

Some chemical properties of the seawater used in this study are shown in Table 1. Irrigation was done (30 days after sowing) using seawater with two dilutions to attain salinity levels of 2,500 and 5,000 ppm. Tap water with salt content of 253 ppm was used as control. Each treatment had six replicates. Potassium dihydrogen phosphate (KH_2P0_4) at either 50 or 100 mg L^{-1} concentration was sprayed at 20 and 30 days after planting.

Sampling and Analysis

Representative soil and plant samples were taken from pots at harvest stage. Plant samples were cleaned and dried in an oven at 70°C for 24 hours and ground in a stainless steel mill. Chemical analyses were carried out according to the methods described by Cottenie et al. (1982).

Anatomical Study

Representative samples from three replicates of treatments were used for an anatomical evaluation. Fully expanded leaf from the seventh internode of the main stem was sampled eight weeks after planting. Samples were preserved and fixed in FAA solution (10 ml formalin + 5 ml glacial acetic acid + 35 ml distilled water + 50 ml 95% ethyl alcohol) for two days. Samples were hydrated and cleared in butyl alcohol series (Willey 1971) and embedded in paraffin wax (56–58°C melting point). Cross sections, 20 μm in thickness, were cut using a rotary microtome with Haupt's adhesive and stained with crystal violet-erythrosine combination (Sass 1961), cleared in carbolxylene and mounted in Canada balsam and microscopically examined. Measurement data were taken using calibrated eyepiece micrometer, and averages of 10 readings were calculated.

Data Analysis

The data obtained were subjected to an analysis of variance (ANOVA) to test significance of treatments. Least significant difference (LSD) was calculated to test statistical significance of the differences in means according to Snedecor and Cochran (1981).

RESULTS AND DISCUSSION

Growth and Yield Parameters

Plant dry weight, plant height, leaf area, and number of leaves per plant were significantly lower for sorghum plants irrigated by saline water as compared with those of the plants irrigated with tap water (Table 2). Grain yield decreased

TABLE 2 Some Growth Parameters and Yield of Sorghum Plants, cv. 'Dorado,' as Influenced by Foliar Application of P and K Under Irrigation with Different Salinity Water

Treatments					Shoot weight (g/plant)		
Salinity ppm	Foliar PK ppm	Plant hight (cm)	No of green leaves	Leaf area (cm^2/plant)	fresh	dry	Grain yield (g/plant)
Tap Water[1]	0	115.0	7.0	171.6	90.4	36.5	22.2
	50	123.0	7.7	188.3	107.6	43.5	30.7
	100	134.6	8.7	203.6	121.4	48.8	32.7
2,500	0	91.2	5.7	135.3	66.1	26.6	16.3
	50	103.3	6.7	170.6	101.7	41.0	27.4
	100	129.3	7.3	175.7	115.1	46.5	29.2
5,000	0	85.0	5.7	122.0	54.0	21.8	13.8
	50	93.6	5.7	149.0	87.2	35.6	22.3
	100	112.9	6.7	166.3	105.4	42.5	24.0
Mean Salinity							
Tap Water		124.2	7.8	187.8	106.5	42.9	28.5
2,500 ppm		107.9	6.6	160.5	94.3	38.0	24.3
5,000 ppm		97.0	6.0	145.8	82.2	33.3	20.0
Mean Foliar PK							
0		97.1	6.1	143.0	70.2	28.3	17.4
50 ppm		106.7	6.7	169.3	98.8	40.0	26.8
100 ppm		125.7	7.6	181.9	114.0	45.9	28.6
LSD at 0.05							
Salinity		2.07	0.56	5.36	3.77	4.87	1.45
Foliar PK		1.36	0.31	2.91	8.76	5.77	2.05
Salinity × Foliar PK		3.38	NS	4.75	NS	NS	NS

[1]Tap water salt content = 253 ppm.

by 15% to 30% in the plants irrigated with saline water as compared with that of the plants irrigated with tap water. The corresponding reduction in the shoot biomass (dry-weight basis) was 11% to 22%. These results confirm the hazardous effects of salinity on sorghum biomass and grain yields. Salinity affects growth of plants through reduced water uptake, reduced metabolic activities caused by Na^+ and $C1^-$ toxicity, and nutrient deficiency caused by antagonism between the ions (Lacerda et al. 2003). Katerji et al. (2009) reported that wheat biomass and yield were reduced when the soil salinity (ECe) was greater than 5.8 dS m^{-1}. This reduction was caused by a decline in grain setting per ear caused by salinity. In barley, grain yield was not reduced across different salinity levels, ranging from 0.9 to 9.8 dS m^{-1}; however, the straw yield was reduced with salinity (Katerji et al. 2009).

Macronutrients in Sorghum Leaves and Grain

Concentrations of Na in sorghum leaves and grain significantly increased in plants irrigated with saline water, as compared with those of the

TABLE 3 Concentrations of Various Macronutrients in Sorghum Leaves, cv. 'Dorado,' as Influenced by Foliar Application of P and K Under Irrigation with Different Salinity Water

		Concentrations (%) sorghum leaves				
Salinity ppm	Foliar PK ppm	N	P	K	Na	Ca
Tap Water[1]	0	1.16	0.33	2.43	0.81	1.15
	50	1.56	0.39	2.53	0.74	1.21
	100	2.11	0.45	2.57	0.65	1.26
2,500	0	1.08	0.25	2.14	0.93	1.15
	50	1.27	0.29	2.18	0.86	1.10
	100	1.52	0.32	2.39	0.85	1.09
5,000	0	1.05	0.09	1.57	1.00	1.03
	50	1.20	0.14	1.86	0.98	1.00
	100	1.32	0.19	1.92	0.93	0.81
Mean Salinity						
Tap Water		1.61	0.39	2.51	0.73	1.21
2,500 ppm		1.24	0.27	2.23	0.88	1.11
5,000 ppm		1.19	0.13	1.78	0.97	0.94
Mean Foliar PK						
0		1.10	0.22	2.05	0.91	1.11
50 ppm		1.34	0.27	2.19	0.86	1.10
100 ppm		1.65	0.32	2.29	0.81	1.05
LSD at 0.05						
Salinity		0.093	0.023	0.021	0.039	0.014
Foliar PK		0.097	0.029	0.024	0.032	0.011
Salinity × Foliar PK		0.159	NS	0.029	NS	0.016

[1]Tap water salt content = 253 ppm.

plants irrigated with tap water (Tables 3 and 4). This could be attributed to inefficient utilization of the absorbed nutrients and/or poor response to fertilizer application under saline conditions. These results confirm the reports of Barrett-Lennard (2003) and Shi and Cheng (2005).

Lacerda et al. (2005) revealed that salinity increased Na^+ or Na^+/K^+ and Na^+/Ca^{2+} ratios in wheat leaves. Ahmed et al. (2000) demonstrated that concentrations of N, Ca, and Na were high, whereas those of P, K, and Mg were low when some sorghum cultivars were grown on a saline clay soil. The physiological responses of plants to a combination of salt and alkalinity were more complex than those for salt stress alone. Lacerda et al. (2003) reported that concentration of Na^+ increased and that of K^+ decreased in plants stressed by salt. Furthermore, high levels of Na^+ decreased K^+ concentration in sorghum plants; hence, increased Na^+/K^+ ratio. Results of sorghum leaves and grain analyses (Tables 3 and 4) revealed that concentrations of N, P, K, and Ca decreased when the plants were irrigated with 2,500 ppm saline water as compared with those of the plants irrigated with

TABLE 4 Concentrations of Various Macronutrients in Sorghum Grains, cv. 'Dorado', as Influenced by Foliar Application of P and K Under Irrigation with Different Salinity Water

Treatments		Concentrations of (%) in sorghum grain				
Salinity ppm	Foliar PK ppm	N	P	K	Na	Ca
Tap Water[1]	0	1.33	0.42	1.66	0.63	0.75
	50	1.44	0.46	1.95	0.56	0.85
	100	1.63	0.55	2.13	0.51	0.93
2,500	0	1.13	0.36	1.38	0.67	0.63
	50	1.25	0.37	1.49	0.55	0.68
	100	1.34	0.38	1.53	0.57	0.75
5,000	0	0.84	0.19	1.16	0.85	0.53
	50	1.22	0.24	1.27	0.66	0.55
	100	1.29	0.29	1.34	0.61	0.59
Mean Salinity						
Tap Water		1.47	0.48	1.91	0.57	0.84
2500 ppm		1.24	0.37	1.47	0.60	0.69
5000 ppm		1.12	0.24	1.25	0.71	0.56
Mean Foliar PK						
0		1.10	0.32	1.40	0.72	0.64
50 ppm		1.30	0.36	1.57	0.59	0.69
100 ppm		1.42	0.41	1.67	0.56	0.76
LSD at 0.05						
Salinity		0.025	0.010	0.040	0.023	0.035
Foliar PK		0.057	0.020	0.046	0.021	0.022
Salinity × Foliar PK		0.092	0.029	0.050	0.029	0.037

[1]Tap water salt content = 253 ppm.

tap water. These concentrations further decreased when the plants were irrigated with 5,000 ppm saline water.

Effects of Foliar Fertilization of P and K

Foliar application of P and K increased concentrations of P and K in the leaves as well as in the grain (Tables 3 and 4). The magnitude of the increase in concentrations was similar for both increments in P and K concentrations. Furthermore, concentrations of N in the leaves and grain also increased with foliar application of P and K. Concentration of Ca decreased in the leaves, whereas it increased in the grain with increasing rates of foliar P and K application. Concentration of Na, however, decreased both in the leaves and grain with increasing rates of P and K foliar applications. Hussein, Shaaban, and El-Saady (2008) also reported that 100 mg L^{-1} of KH_2P0_4 was most effective in mitigating the negative effects of salinity level of 3.0 dS m^{-1} in irrigation water. Foliar fertilization of P and K appears to overcome the negative effects of salinity, as evident from increased shoot biomass, number of green leaves, and grain yield (Table 2).

Interaction between Salinity of Irrigation Water and Foliar P and K Application

The interaction effects between irrigation-water salinity and foliar fertilization of P and K were significant on concentrations of K, N, and Ca in the leaves, and those of all macronutrients analyzed in the grain (Tables 3 and 4). For example, in the plants irrigated with 5,000 ppm salinity water, concentration of K in the leaves increased by 18% and 22% with an increase in concentration of foliar spray (P and K) at 50 and 100 ppm, respectively, as compared with that without foliar P and K application. The corresponding increases in K concentrations were 4% and 6% for the plants irrigated with tap water. Therefore, plant response to P and K foliar application was greater in the plants subjected to salinity stress as compared with that of the plants under no salinity stress. These results are in agreement with those of Kaya, Higgs, & Kirnak (2001), who reported that K concentration in plant tissues increased with foliar application of P and K under elevated NaCl level. High salinity decreased the concentrations of P and K in the leaves, but these concentrations were enhanced with foliar application of P and K. Jagadeesh et al. (2006) suggested that low rates of foliar-applied P might correct mid-season P deficiency in winter wheat by increasing P-uptake efficiency.

Effects on the Soil Properties

Soil analyses after sorghum harvest indicated soil pH values were 7.45 and 7.68 with irrigation-water salinity of 2,500 and 5,000 ppm, respectively, as compared with 7.33 pH of the soil with tap-water irrigation (Table 5). Salt content in the soil as measured by EC also increased to 2.57 and

TABLE 5 Some Chemical Properties of the Soil after Sorghum Harvest Following Irrigation with Tap Water or Different Salinity Levels Water

Treatments				Macronutrients (mg kg^{-1} soil)			
Salinity (ppm)	Foliar PK (ppm)	pH (1:2.5)	EC (dS m^{-1})	N	P	K	Na
Tap water[1]	0	7.25	1.36	41	14	300	250
	50	7.32	1.41	45	16	325	230
	100	7.41	1.47	47	18	350	210
2,500	0	7.36	2.68	35	11	280	380
	50	7.45	2.59	38	13	310	365
	100	7.55	2.43	38	14	315	360
5,000	0	7.60	4.71	36	10	220	450
	50	7.68	4.56	39	12	280	410
	100	7.75	4.39	42	12	290	395

[1]Tap water salt content = 253 ppm.

4.55 dS m^{-1} with each increment in irrigation-water salinity, as compared with 1.41 dS m^{-1} for the soil with tap-water irrigation. Overall, concentrations of N, P, and K in the soil decreased, whereas those of Na increased with an increase in irrigation-water salinity. These results are in agreement with those of Clark et al. (1999).

Stem Anatomy

Stem diameter decreased by 22% and 32% in the plants grown with saline irrigation water at 2,500 and 5,000 ppm, respectively, as compared with that of the plants grown with tap water irrigation (Table 6). The corresponding reductions in stem-wall thickness were 25% and 40%, whereas those for xylem-vessel diameter were 28% and 31%. Ghoulam, Foursy, and Fares (2002) and Lacerda et al. (2003) found that the harmful effect of salinity was caused by suppressed division and enlargement of cells, narrowing of the xylem vessels, and reduced cell size of both the xylem and phloem. Similar results were obtained by Akram et al. (2002) for stem anatomical characteristics in tomato plants subjected to increasing salinity. Salinity also reduced area of cortex, stele and pith in the roots. Junghans et al. (2006) reported that a decrease in the vessel lumina of two poplar species was associated with increase in wall strength in response to salt stress. Jagadeesh et al. (2006) concluded that low rates of foliar-applied P might correct mid-season P deficiency in winter wheat, and that might result in higher P-use efficiencies. Kaya, Higgs, and Kirnak (2001) and Hussein, Shaaban, and El-Saady

TABLE 6 Effect of Salinity and P and K Foliar Application on the Internal Structure of Sorghum Stem

Treatments		Botanical properties				
				Dimension of vascular bundle		
Salinity (ppm)	Foliar PK (ppm)	Stem diameter (cm)	Stem wall thickness (cm)	Length (cm)	Width (cm)	Xylem vessel diameter (cm)
Tap water[1]	0	0.44	0.0029	0.0107	0.0096	0.0027
	50	0.49	0.0031	0.0108	0.0100	0.0028
	100	0.59	0.0033	0.0110	0.0103	0.0029
2,500	0	0.37	0.0021	0.0095	0.0090	0.0019
	50	0.40	0.0024	0.0099	0.0091	0.0020
	100	0.42	0.0025	0.0100	0.0093	0.0021
5,000	0	0.30	0.0018	0.0090	0.0085	0.0018
	50	0.34	0.0018	0.0094	0.0090	0.0020
	100	0.39	0.0020	0.0097	0.0092	0.0020
LSD at 0.05		0.019	0.00006	0.00007	0.0001	0.00006

[1]Tap water salt content = 253 ppm.

(2008) reported that foliar application of K and P alleviated the harmful effect of saline water on tomato and cowpea plant, respectively.

Leaf Anatomy

The results revealed adverse effects of salinity levels (at either 2,500 or 5,000 ppm) on all leaf anatomical traits, i.e., decrease in thickness of lamina, upper and lower epidermis; length and width of bulliform cell; mesophyll thickness; dimensions of small and large vascular bundle; and xylem vessel (Table 7). All the above leaf anatomical characteristics increased with an increase in concentrations of P and K foliar application at each irrigation water salinity level. The magnitudes of responses to increasing concentrations of P and K foliar fertilization were generally similar across plants irrigated with tap water. Baum, Tran, and Silk (1999) noted that within the growth zone, protozylem and metazylem cells were narrower in sorghum leaves grown under salt stress as compared with those plants subjected to no salt stress. Hu, Schmidhalter, and Hu (2001) reported that reduction in cellular cross section area of wheat leaves subjected to 120 mM NaCl was 32% near the base (5 mm), whereas it was 36% in the 5 to 30 mm region from the leaf base. Hameed et al. (2002) revealed that the thickness of wheat leaf cuticle, epidermis, hypodermis, and number of stomata increased under water stress, whereas stomatal length decreased due to salt stress. Akram et al. (2002) found that salinity increased the number of stomata in tomato but reduced the area of stomata and interveinal distance. Godfrey, Onyango, and Beck (2004) reported that two sorghum varieties appeared to sequester Na^+ predominately in the roots. Saline irrigation water decreased the stem cross-section diameter. The above decreases were due to reduced length and width of parenchymatous tissues, the vascular bundles, and diameter of xylem vessels, as well as thickness of the mesophyll of leaf blade. Potassium foliar application alleviated the harmful effect of saline water on the internal structure of the stem and leaf (Kabir, Karim, & Azad 2007; Hussein, Shaaban, & El-Saady 2008). The supply of mineral ions to the leaf growing region may decline because of lower transpiration rate coupled with reduced ion uptake by the roots, or reduced xylem loading, leading to reduced xylem flow. This, in turn, could lead to inadequate supply of ions to the expanding region, resulting in restricted cell division and/or expansion when plants are grown in high concentration of NaCl in the medium. Therefore, foliar application of nutrients could be one strategy to overcome root uptake and xylem flow of nutrients when plants are subjected to salt stress.

CONCLUSIONS

Application of saline irrigation water (either 2,500 or 5,000 ppm) had negative effects on sorghum plant height, number of green leaves, and shoot

TABLE 7 Effect of Salinity and Foliar Application of P and K on the Internal Structure of Sorghum Leaf

	Salinity of Irrigation Water								
	Tap water			2,500 ppm			5,000 ppm		
	P and K foliar application (ppm)								
Botanical properties	0	50	100	0	50	100	0	50	100
Lamina thickness (cm)	0.0135	0.0143	0.0151	0.0122	0.0128	0.0132	0.0097	0.0103	0.0107
Upper epidermal thickness (cm)	0.0027	0.0032	0.0035	0.0021	0.0024	0.0026	0.0019	0.0020	0.0022
lower epidermal thickness (cm)	0.0023	0.0027	0.0029	0.0020	0.0021	0.0023	0.0017	0.0018	0.0019
Bulliform cell length (cm)	0.0050	0.0051	0.0053	0.0041	0.0043	0.0047	0.0029	0.0032	0.0034
Bulliform cell width (cm)	0.0034	0.0038	0.0043	0.0023	0.0029	0.0031	0.0023	0.0030	0.0026
Mesophyll thickness (cm)	0.0090	0.0102	0.0103	0.0081	0.0090	0.0098	0.0072	0.0078	0.0086
Small Vb's (cm^2)	0.3452	0.2896	0.3600	0.2430	0.2646	0.3074	0.2460	0.2499	0.2615
large Vb's (cm^2)	1.0731	1.1275	1.1589	0.8589	0.9001	0.9184	0.7777	0.8205	0.8705
Xylem vessel in largeVb's (cm^2)	0.0844	0.0484	0.0511	0.0289	0.0309	0.0382	0.0324	0.0361	0.0494
Number of vascular bundle	132	135	137	118	119	125	117	118	123

Tap water salt content = 253 ppm, Vb = Vascular bundle.

weight. The magnitudes of the negative effects were similar at both salinity levels as compared with growth of the plant with tap water irrigation. Foliar application of P and K mitigated the negative effects of salinity on plant growth. Concentrations of P and K in the leaves and in grain decreased with each increment in salinity. Foliar application of P and K at 100 ppm mitigated the negative affects of salinity completely at 2,500 ppm; however, the above effect was somewhat partial at 5,000 ppm salinity. The beneficial effects of P and K foliar application to plants under salinity stress were also evident on the stem diameter, stem-wall thickness, and length and width of vascular bundle. Increasing level of salinity also decreased diameter of xylem vessel. Foliar application of P and K, however, had marginal beneficial effects in mitigating the adverse effects of salinity on xylem vessel size at both concentrations. This research demonstrated beneficial effects of supplemental application of P and K, preferably as foliar spray, to overcome the negative effects of irrigation with saline water.

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